SETUP FOR CHARACTERIZATION OF INDIRECT CONVERTING X-RAY DETECTORS

A.H. Ozdiev, D.A. Karpov
Scientific Supervisor: Prof., Dr. Yu.Yu. Kryuchkov
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: ozdiev@tpu.ru

СИСТЕМА ОЦЕНКИ ПАРАМЕТРОВ НЕПРЯМЫХ ДЕТЕКТОРОВ РЕНТГЕНОВСКОГО ИЗЛУЧЕНИЯ

А.Х.Оздиев, Д.А. Карпов
Научный руководитель: профессор, д.ф.-м.н. Ю.Ю. Крючков
Национальный исследовательский Томский политехнический университет,
Россия, г.Томск, пр. Ленина, 30, 634050
E-mail: ozdiev@tpu.ru

Аннотация. *Современные источники рентгеновского излучения позволяют изучение динамических процессов в таких областях как биология, медицина, материаловедение и тд. Точность процесса измерения напрямую зависит от возможностей системы детектирования. Быстродействующие цифровые камеры являются ключевыми элементами непрямой системы детектирования. Данные камеры обладают набором параметров влияющих на качество получаемых данных. Два основных типа быстродействующих камер, используемых в системах непрямого детектирования, отличаются только архитектурой сенсора: ПЗС и КМОП сенсоры. В настоящей работе мы представляем установку для получения характеристик данных сенсоров Visible Light Setup (VLS), разработанную в Институте Синхротронного Излучения Технологического Института Карлсруэ. Собранная установка позволяет проводить оценку таких характеристик камер, как: неоднородности сенсора, дефектные пиксели, линейность, шумовые характеристики, спектральная чувствительность и тд. Результаты работы позволяют точную оценку параметров камеры непосредственно перед проведением эксперимента на станциях синхротронного излучения благодаря дополнительно произведенной автоматизации процесса оценки и обработки данных.*

Current state of X-ray radiation sources allows investigation of dynamic processes. Dynamic processes studied at synchrotron radiation sources require fast frame rate from the detector system and its ability to keep with high flux imposed by the source of radiation. This can be realized by using Indirect converting X-ray detectors. The main component of indirect converting detector is an integrating camera. Majority of integrating cameras are based on either CCD or CMOS sensor architecture. One of the main characteristics of available CCD and CMOS cameras are linearity, noise, sensor non-uniformities, and spectral response. Camera manufacturer provides specifications of the cameras with the required characteristics. However the specifications are given for the product line and not for each individual camera. Extracting the parameters from individual devices will allow better experimental planning and better understanding of the final results. Moreover indirect converting detector system poses a modular system which can be finely configured for the demand of a particular experiment. Knowing the specifications of the system components allows construction of the mathematical model for the system and it's tuning for the experiment needs.

There are two different approaches for the cameras comparison. One can perform straightforward side-by-side test of different cameras. The side-by-side approach is time consuming and generally not quantitive and reproducible. Another possible solution is a standardized test procedure based on qualitative and quantitative measurements. Photon transfer method (PTM) is the method that allows cameras comparison according to the measurements of their most critical parameters. In the PTM the camera is considered as a black box and all the parameters are derived based on utilization of system theory approach.

The mathematical model of camera sensor can be described as following:

$$\sigma_y^2 = K^2\sigma_d^2 + \sigma_q^2 + K(\mu_y - \mu_{y.dark}),$$
$$\mu_y = \mu_{y.dark} + R\mu_p$$

where σ^2_y is variance of the noise, σ^2_d is dark noise variance, σ^2_q is quantization noise, μ_y is mean gray value, $\mu_{y.dark}$ is mean dark value, R is responsivity, and K is overall system gain [1]. The equation above is based on a physical sensor model and essentially shows the process where a number of photons incident on a sensor surface are converted into digital electronic signal with noise characteristics influencing the signal quality. The basic idea of PTM is to measure input signal on the camera sensor and while varying it investigate the response characteristics of the sensor by evaluating the output signal under certain assumptions.

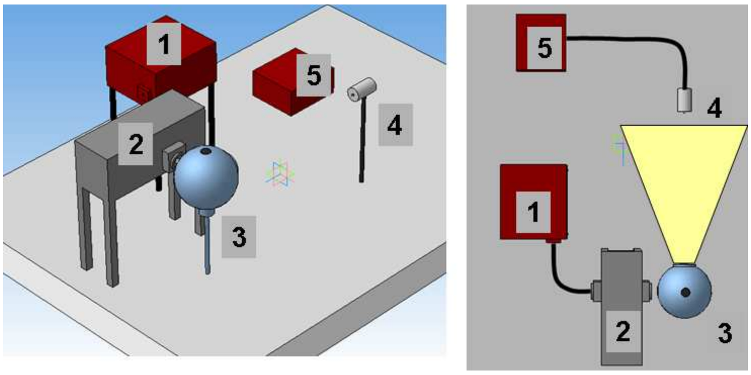

Fig. 1. Scheme of the VLS setup

To implement the measuring principles of PTM a Visible Light Setup (VLS) was designed and assembled at the Detector Laboratory of ANKA synchrotron light source. Figure 1 shows the arrangement of the setup. As a source of visible light the halogen light source (1) was selected due to the simplicity of utilization and broad wavelength spectrum. The narrow wavelength range is then selected by monochromator (2) and directed into the integrating sphere (3). The purpose of integrating sphere is to remove spatial characteristics of light beam and to produce uniform illumination of the calibrated photodiode (4), which is used to evaluate amount of photons per unit area at a given distance. Entering the integrating sphere light undergoes multiple reflections from highly diffusing surface which results in vanished spacial characteristics of light and the distribution of photons can be assumed to be Poisson-like.

Two important calibration procedures were performed to assure the high precision of the system. The first measurement performed was to evaluate time stability of the system and homogeneity of radiation over area at which sensor under test will be then characterized. Results of the measurements show temporal instability of

0.61 % [2] and the inhomogeneity of illumination over 4 cm by 4 cm area was measured to be 3%. Which lies within reasonable range according to the standard for camera specifications produced by European Machine Vision Association (EMVA) [3].

Another important calibration was the estimation of photodiode linearity. The measurement was performed by varying the distance between output of integrating sphere and a sensor of the photodiode. The evaluation was then carried out by fitting how close is the intensity distribution to a reciprocal law of light intensity decay. The results show high linearity of the photodiode used in the system [4].

To ensure high reproducibility of the measurement results and to reduce complexity of operation for the end-users the automation of the setup was performed based on the standardized hierarchy of classes and API which allows independent access to the device components. We've used Concert Control System [5] to integrate setup components and to write algorithms for automatic measurement and evaluation procedures.

Two identical models of PCO cameras were used to show system performance. We have used high-end PCO.edge cameras which are one of the best available cameras according to the dynamic range and noise properties. The measurement results are shown in the Table 1.

The results for camera characterization show that the specifications differ from the real camera performance. Knowing the camera characteristics allows better detectors and experiment tuning especially at the measurements of dynamic processes performed at the edge of system capabilities. Designed setup allows characterization of the cameras directly before the beamline measurements since the automation procedure allows the test run and evaluation to be carried out within 1.5 hour timeframe. Further development of the system will include detector optics tests and modeling of the experiment parameters.

Table 1

Measurement results for PCO.edge cameras

	Parameter	*Specifications*	Camera 1	*Camera 2*
1	Quantum efficiency, η	54 %	59.8 %	64.9 %
2	Sensitivity threshold, $\mu_{p.min}$	Not Specified	2.86 photons	2.62 photons
3	Dynamic range, DR	27 000	18 198	18 365
4	Full-well capacity, $\mu_{e.sat}$	Not Specified	31 124 e^-	31 228 e^-
5	Dark current noise, σ_d	1.1 e^-	2.26 e^-	2.29 e^-

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